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(54) Densitometer for measuring developability.

(57) An infrared densitometer which measures the reflectivity of a selected region on a moving photoconductive belt (10) covered at least partially with marking particles. Collimated light rays are projected onto the selected region of the moving photoconductive member with or without marking particles thereon. The light rays reflected from the selected region of the moving photoconductive member are collected and directed onto a photodiode array (106). The photodiode array generates electrical signals proportional to the diffuse component of the total reflectivity of the selected region of the photoconductive member with and without marking particles thereon. Circuitry determines a control signal as a function of the difference in electrical signals.

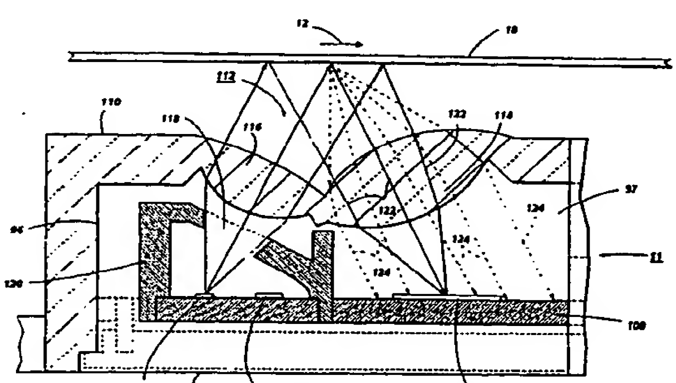

FIG. 3

EP 0 414 504 A2

DENSITOMETER FOR MEASURING DEVELOPABILITY

This invention relates generally to apparatus for measuring the reflectivity of a surface covered at least partially with particles, and more particularly concerns a densitometer for use in measuring developability in an elctrophotographic printing machine by detecting the reflectivity of a selected region on the photoconductive member.

In an electrophotographic printing machine, the photoconductive member is charged to a substantially uniform potential to sensitize the surface thereof. The charged portion of the photoconductive member is exposed to a light image of an original document being reproduced. Exposure of the charged photoconductive member selectively dissipates the charge thereon in the irradiated areas. This records an electrostatic latent image on the photoconductive member corresponding to the informational areas contained within the original document being reproduced. After the electrostatic latent image is recorded on the photoconductive member, the latent image is developed by bringing marking or toner particles into contact therewith. This forms a powder image on the photoconductive member which is subsequently transferred to a copy sheet. The copy sheet is heated to permanently affix the marking particles thereto in image configuration.

Various types of development systems have hereinbefore been employed. These systems utilize two component developer mixes or single component developer materials. Typical two component developer mixes employed are well known in the art, and generally comprise dyed or colored thermoplastic powders, known in the art as toner particles, which are mixed with coarser carrier granules, such as ferromagnetic granules. The toner particles and carrier granules are selected such that the toner particles acquire the appropriate charge relative to the electrostatic latent image recorded on the photoconductive surface. When the developer mix is brought into contact with the charged photoconductive surface the greater attractive force of the electrostatic latent image recorded thereon causes the toner particles to transfer from the carrier granules and adhere to the electrostatic latent image.

Multi-color electrophotographic printing is substantially identical to the foregoing process of black and white printing. However, rather than forming a single latent image on the photoconductive surface, successive latent images corresponding to different colors are recorded thereon. Each single color electrostatic latent image is developed with toner particles of a color complimentary thereto. This process is repeated a plurality of cycles for differently colored images and their respective complementarily colored toner particles. For example, a red filtered light image is developed with cyan toner particles, while a green filtered light image is developed with magenta toner particles and a blue filtered light image with yellow toner particles. Each single color toner powder image is transferred to the copy sheet superimposed over the prior toner powder image. This creates a multi-layered toner powder image on the copy sheet. Thereafter, the multi-layered toner powder image is permanently affixed to the copy sheet creating a color copy. An illustrative electrophotographic printing machine for producing color copies is the Model No. 1005 made by the Xerox Corporation.

It is evident that in printing machines of this type, toner particles are depleted from the developer mixture. As the concentration of toner particles decreases, the density of the resultant copy degrades. In order to maintain the copies being reproduced at a specified minimum density, it is necessary to regulate the concentration of toner particles in the developer mixture. This is achieved by a closed loop servo system which regulates developability. Developability, as it pertains to an electrophotographic printing machine is the ability of the developer mixture to develop the latent image with at least a minimum specified density. It has long been recognized that a closed loop system, which regulates developability by measuring the density of the powder image developed on the photoconductive surface, optimizes cost and performance. This is due to the relative stability of the transfer and fusing processes. Also, by modulating one parameter, such as toner particle concentration, compensation for factors contributing to low copy quality, such as photoreceptor dark decay fluctuation and developer aging, can be partially accomplished. The use of densitometers for measuring the optical density of black toner particles is well known. However, densitometers used for black toner particles are generally unsuitable for use with colored toner particles. Densitometers of this type are generally sensitive to the large component of diffusely reflected flux in the infrared from colored toner particles which gives false density measurements . Various approaches have been used to measure density. The following disclosures are of interest:

US-A-4,553,033
Patentee: Hubble, III et al.
Issued: November 12, 1985
US-A-4,750,838
Patentee: De Wolf et al.
Issued: June 14, 1988

US-A-4,796,065
Patentee: Kanbayashi
Issued: January 3, 1989
US-A-4,799,082
Patentee: Suzuki
Issued: January 17,1989
US-A-4,801,980
Patentee: Arai et al.
Issued: January3, 1989
European Patent Application No. 0 360 484
Applicant: Xerox Corportation.
Filed: September 12, 1989

Those disclosures may be briefly summarized as follows:

US-A-4,553,033 discloses an infrared reflectance densitometer including a light emitting diode, a collimating lens through which light is projected to a photosensitive surface, a collector lens and a field lens through which reflected light is focused onto a signal photodiode, and a control photodiode onto which a portion of reflected light is directed to control light output. The amount of light received on the signal photodiode is a measurement of the reflectance of the surface of the photoreceptor which, in turn, is proportional to the density of the toner particles thereon.

US-A-4,750,838 describes an opotoelectric circuit for measuring differences in optical densities of an image carrier. An LED illuminates a test area. The light reflected from the surface is sensed by a phototransistor. The linear output of the LED is proportional to the image density. The circuit has a voltage follower, output transistor, amplifier and differential amplifier for controlling the image density measurements. The circuit has a range of density sensitivities between 0.5 and 1.5 mg/cm^2.

US-A-4,796,065 discloses an apparatus for detecting image density in an image forming machine by sensing either regular reflection or scattered reflection. A circuit having light emitting elements (LEDs or phototransistors), a pair of sensors, and a comparator is used for determining image density.

US-A-4,799,082 describes an electrostatic reproducing apparatus having a light source and detector for detecting color toner density. A sensor is driven by a circuit which contains a power source, a safety resistor, operational amplifier, comparator and voltage dividing resistors for producing a signal representative of the light reflected from the image.

US-A-4,801,980 discloses a toner density control apparatus which compares an image density of a reference image with a predetermined level to control density. Voltage to a light emitting element is controlled by the circuit which includes a sensor correction portion.

European Patent Application No. 0360484 describes an infrared densitometer which measures the reduction in the specular component of reflectivity as toner particles are progressively deposited on a moving photoconductive belt. Collimated light rays are projected onto the toner particles. The light rays reflected from at least the toner particles are collected and directed onto a photodiode array. The photodiode array generates electrical signals proportional to the total flux and the diffuse component of the total flux of the reflected light rays. Circuitry compares the electrical signals and determines the difference therebetween to generate an electrical signal proportional to the specular component of the total flux of the reflected light rays.

According to the present invention, there is provided an apparatus for measuring the reflectivity of a selected region of a surface covered at least partially by particles. The apparatus includes means for generating a first signal proportional to the diffuse component of the total reflectivity of the selected region of a surface covered at least partially by particles and a first reference signal proportional to the diffuse component of the total reflectivity of the selected region of the surface without particles thereon. Means are provided for determining a control signal as a function of the difference between the first signal and the first reference signal.

The control signal can be used to indicate the density of the particles on the said surface and thereby to regulate the rate at which particles are deposited on the surface. The present invention accordingly also provides apparatus for measuring the density of particles on a selected region of a surface, comprising:

means operable to detect light reflected from the surface and to generate a first signal proportional to the diffuse component of the total reflectivity of the said selected region when carrying the said particles, and a first reference signal proportional to the diffuse componenet of the total reflectivity of a region of the surface without particles thereon; and

means for generating a measurement signal as a function of the difference between the first signal and the first reference signal, said measurement signal indicating the density of the said particles.

The measurement signal can be used in particular to indicate if a specified minimum density of particles on the surface is not maintained.

In accordance with another aspect of the present invention, there is provided an electrophotographic printing machine of the type in which the reflectivity of a selected region of a moving photoconductive member covered at least partially by marking particles is detected. The machine includes means for generating a first signal proportional to the diffuse component of the total reflectivity of the selected region of the photoconductive member covered at least partially by mark-

ing particles and a first reference signal proportional to the diffuse component of the total reflectivity of a region of the photoconductive member without marking particles thereon. Means are provided for determining a control signal as a function of the difference between the first signal and the first reference signal.

Another aspect of the present invention is an infrared densitometer for measuring the reflectivity of a selected region of a moving photoconductive member covered at least partially with marking particles. The densitometer includes a collimating lens and a light source positioned to project light rays through the collimating lens onto the moving photoconductive member. A collector lens is positioned to receive the light rays reflected from the moving photoconductive member. A photosensor array is positioned to receive the light rays transmitted through the collector lens and generates a first signal proportional to the diffuse component of the total reflectivity of the selected region of the photoconductive member covered art least partially with marking particles and a first reference signal proportional to the diffuse component of the total reflectivity of the region of the photoconductive member without marking particles thereon. Control circuitry, electrically connected to the photosensor array, determines a control signal as a function of the difference between the first signal and the first reference signal.

Still another aspect of the present invention is a method of measuring the reflectivity of a selected region of a photoconductive member covered at least partially with diffusely reflecting marking particles. The method includes the steps of generating reference voltages proportional to the specular and diffuse components of the total reflectivity of the selected region of the photoconductive member without marking particles thereon and covered at least partially with black marking particles. A constant of proportionality is determined as a function of the reference voltages generated in the step of generating and the diffuse reflectivity of the black marking particles. A voltage is generated proportional to the diffuse component of the total reflectivity of the selected region of the photoconductive member covered at least partially with diffusely reflecting marking particles. The portion of the selected region of the photoconductive member that is covered at least partially with diffusely reflecting marking particles is determined as a function of the constant of proportionality and the voltage proportional to the diffuse component of the total reflectivity of the portion of the region of the photoconductive member without marking particles thereon.

By way of example only, an embodiment of the invention will be described with reference to the drawings, in which:

Figure 1 is a schematic elevational view depicting an electrophotographic printing machine incorporating an infrared densitometer in accordance with the present invention;

Figure 2 is a schematic perspective view showing the densitometer used in the Figure 1 printing machine;

Figure 3 is a fragmentary, sectional elevational view of the Figure 2 densitometer;

Figure 4 is an enlarged plan view of the photodiode array used in the Figure 2 densitometer: and

Figure 5 is a block diagram of the control logic associated with the Figure 2 densitometer.

In the drawings, like reference numerals have been used throughout to designate identical elements. Figure 1 schematically depicts the various components of an illustrative electrophotographic printing machine incorporating an infrared densitometer in accordance with the present invention. It will become evident from the following discussion that the densitometer is equally well suited for use in a wide variety of electrostatographic printing machines, and is not necessarily limited in its application to the particular electrophotographic printing machine shown herein.

Inasmuch as the art of electrophotographic printing is well known, the various processing stations employed in the Figure 1 printing machine are shown schematically only and their operation will be described briefly with reference thereto.

As shown in Figure 1, the electrophotographic printing machine employs a photoreceptor, i.e. a photoconductive belt 10. Preferably, the photoconductive belt 10 is made from a photoconductive material coated on a grounding layer, which, in turn, is coated on an anti-curl backing layer. The photoconductive material is made from a transport layer coated on a generator layer. The transport layer transports positive charges from the generator layer. The interface layer is coated on the grounding layer. The transport layer contains small molecules of di-m-tolydiphenylbiphenyldiamine dispersed in a polycarbonate. The generation layer is made from trigonal selenium. The grounding layer is made from a titanium coated Mylar. The grounding layer is very thin and allows light to pass therethrough. Other suitable photoconductive materials, grounding layers, and anti-curl backing layers may also be employed. Belt 10 moves in the direction of arrow 12 to advance successive portions of the photoconductive surface sequentially through the various processing stations disposed about the path of movement thereof. Belt 10 is entrained about idler roller 14 and drive roller 16. Idler roller 14 is mounted rotatably so as to rotate with belt 10. Drive roller 16 is rotated by a motor coupled thereto by suitable means such as a belt

drive. As roller 16 rotates, it advances belt 10 in the direction of arrow 12.

Initially, a portion of photoconductive belt 10 passes through charging station A. At charging station A, a corona generating device, indicated generally by the reference numeral 18 charges photoconductive belt 10 to a relatively high, substantially uniform potential.

Next, the charged photoconductive surface is rotated to exposure station B. Exposure station B includes a moving lens system, generally designated by the reference numeral 22, and a color filter mechanism, shown generally by the reference numeral 24. An original document 26 is supported stationarily upon a transparent viewing platen 28. Successive incremental areas of the original document are illuminated by means of a moving lamp assembly, shown generally by the reference numeral 30. Mirrors 32, 34 and 36 reflect the light rays through lens 22. Lens 22 is adapted to scan successive areas of illumination of platen 28. The light rays from lens 22 are transmitted through filter 24 and reflected by mirrors 38, 40, and 42 on to the charged portion of photoconductive belt 10. Lamp assembly 30, mirrors 32, 34 and 36, lens 22, and filter 24 are moved in a timed relationship with respect to the movement of photoconductive belt 10 to produce a flowing light image of the original document on photoconductive belt 10 in a non-distorted manner. During exposure, filter mechanism 24 interposes selected color filters into the optical light path of lens 22. The color filters operate on the light rays passing through the lens to record an electrostatic latent image, i.e. a latent electrostatic charge pattern, on the photoconductive belt corresponding to a specific color of the flowing light image of the original document. Exposure station B also includes a test area generator, indicated generally by the reference numeral 43, comprising a light source to project a test light image onto the charged portion of the photoconductive surface in the inter-image region, i.e. the region between successive electrostatic latent images recorded on photoconductive belt 10, to record a test area. The test area, as well as the electrostatic latent image recorded on the photoconductive surface of belt 10 are developed with toner particles at the development stations.

After the electrostatic latent image and test area have been recorded on photoconductive belt 10, belt 10 advances them to development station C. Development station C includes four individual developer units generally indicated by the reference numerals 44,46,48 and 50. The developer units are of a type generally referred to in the art as "magnetic brush development units." Typically, a magnetic brush development system employs a magnetizable developer material including magnetic carrier granules having toner particles adhering triboelectrically thereto. The developer material is continually brought through a directional flux field to form a brush of developer material. The developer particles are continually moving so as to provide the brush consistently with fresh developer material. Development is achieved by bringing the brush of developer material into contact with the photoconductive surface. Developer units 44, 46, and 48, respectively, apply toner particles of a specific color which corresponds to the compliment of the specific color separated electrostatic latent image recorded on the photoconductive surface. The color of each of the toner particles is adapted to absorb light within a preselected spectral region of the electromagnetic wave spectrum corresponding to the wave length of light transmitted through the filter. For example, an electrostatic latent image formed by passing the light image through a green filter will record the red and blue portions of the spectrums as areas of relatively high charge density on photoconductive belt 10, while the green light rays will pass through the filter and cause the charge density on the photoconductive belt 10 to be reduced to a voltage level ineffective for development. The charged areas are then made visible by having developer unit 44 apply green absorbing (magenta) toner particles onto the electrostatic latent image recorded on photoconductive belt 10. Similarly, a blue separation is developed by developer unit 46 with blue absorbing (yellow) toner particles, while the red separation is developed by developer unit 48 with red absorbing (cyan) toner particles. Developer unit 50 contains black toner particles and may be used to develop the electrostatic latent image formed from a black and white original document. The yellow, magenta and cyan toner particles are diffusely reflecting particles. Each of the developer units is moved into and out of the operative position. In the operative position, the magnetic brush is closely adjacent the photoconductive belt, while, in the non-operative position, the magnetic brush is spaced therefrom. During development of each electrostatic latent image only one developer unit is in the operative position, the remaining developer units are in the non-operative position. This insures that each electrostatic latent image and successive test areas are developed with toner particles of the appropriate color without co-mingling. In Figure 1, developer unit 44 is shown in the operative position with developer units 46, 48 and 50 being in the non-operative position. The developed test area passes beneath an infrared densitometer, indicated generally by the reference numeral 51. Infrared densitometer 51 is positioned adjacent the photoconductive surface of belt 10 to generate electrical signals proportional to the developed toner mass of the test area. The

detailed structure of densitometer 51 will be described hereinafter with reference to Figures 2 through 5, inclusive.

After development, the toner image is moved to transfer station D where the toner image is transferred to a sheet of support material 52, for example plain paper. At transfer station D, the sheet transport apparatus, indicated generally by the reference numeral 54, moves sheet 52 into contact with photoconductive belt 10. Sheet transport 54 has a pair of spaced belts 56 entrained about three rolls 58, 60 and 62. A gripper 64 extends between belts 56 and moves in unison therewith. Sheet 52 is advanced from a stack of sheets 72 disposed on tray 74. Feed roll 77 advances the uppermost sheet from stack 72 into the nip defined by forwarding rollers 76 and 78. Forwarding rollers 76 and 78 advance sheet 52 to sheet transport 54. Sheet 52 is advanced by forwarding rollers 76 and 78 in synchronism with the movement of gripper 64. In this way, the leading edge of sheet 52 arrives at a preselected position to be received by the open gripper 64. The gripper then closes securing the sheet thereto for movement therewith in a recirculating path. The leading edge of the sheet is secured releasably by gripper 64. As the belts move in the direction of arrow 66, the sheet 52 moves into contact with the photoconductive belt, in synchronism with the toner image developed thereon, at the transfer zone 68. A corona generating device 70 sprays ions onto the backside of the sheet so as to charge the sheet to the proper magnitude and polarity for attracting the toner image from photoconductive belt 10 thereto. Sheet 52 remains secured to gripper 64 so as to move in a recirculating path for three cycles. In this way, three different color toner images are transferred to sheet 52 in superimposed registration with one another. Thus, the aforementioned steps of charging, exposing, developing, and transferring are repeated a plurality of cycles to form a multicolor copy of a colored original document.

After the last transfer operation, grippers 64 open and release sheet 52. Conveyor 80 transports sheet 52, in the direction of arrow 82, to fusing station E where the transferred image is permanently fused to sheet 52. Fusing station E includes a heated fuser roll 84 and a pressure roll 86. Sheet 52 passes through the nip defined by fuser roll 84 and pressure roll 86. The toner image contacts fuser roll 84 so as to be affixed to sheet 52. Thereafter, sheet 52 is advanced by forwarding roll pairs 88 to catch tray 90 for subsequent removal therefrom by the machine operator.

The last processing station in the direction of movement of belt 10, as indicated by arrow 12, is cleaning station F. A rotatably mounted fibrous brush 92 is positioned in cleaning station F and maintained in contact with photoconductive belt 10 to remove residual toner particles remaining after the transfer operation. Thereafter, lamp 94 illuminates photoconductive belt 10 to remove any residual charge remaining thereon prior to the start of the next successive cycle.

Referring now to Figures 2 and 3, there is shown infrared densitometer 51 in greater detail. Densitometer 51 includes a generally rectangularly shaped molded housing 96 made preferably from an acrylic material or any other suitable optically transparent material. Housing 96 defines a chamber 97. A cover 98 encloses the bottom of housing 96. A printed circuit wiring board 100 is mounted between cover 98 and housing 96 in chamber 97. Printed circuit board 100 supports a suitable light emitting diode (LED) 102 for providing light rays to illuminate the marking particles adhering to the photoconductive surface of belt 10. A control photodiode 104 and a photodiode array 106 are also mounted on printed circuit board 100. The details of photodiode array 106 will be described hereinafter with reference to Figure 4. Connector 108 is also mounted on printed circuit board 100. An integrated circuit chip, indicated generally by the reference numeral 107, is electrically connected to LED 102, photodiode 104 and photodiode array 106 to provide drive current to LED 102 and to process the signals from photodiode 104 and photodiode array 106. The top surface 110 of housing 96 defines a V-shaped recess, generally indicated by the reference numeral 112. One surface of the V-shaped recess 112 supports a condenser lens 116 which is an integral collimating lens. The other surface of the V-shaped recess 112 supports another condenser lens 114 which is an integral collector lens. LED 102 generates near infrared light rays which are transmitted through an aperture 118 in housing 120 onto condenser lens 116. Condenser lens 116 collimates the light rays and focuses the light rays onto the marking or toner particles deposited on the test area recorded on the photoconductive surface of belt 10. Photodiode 104 is positioned to receive a portion of the LED radiant flux reflected from the walls of housing 120. The output signal from photodiode 104 is compared with a reference signal and the resultant error signal used to regulate the input current to LED 102 to compensate for LED aging and thermal effects. The reflected light rays are collected by condenser lens 114 and directed onto the surface of photodiode array 106. The specular component of the reflected light rays or flux, as shown by arrows 122, is focused on a small spot on surface of the central segment of photodiode array 106. The diffuse components of the reflected light rays or flux, as shown by arrows 124, flood the entire surface of photodiode array 106. Further details of

the structure of the densitometer, exclusive of photodiode array 106, may be found in U.S. Patent No. 4,553,033 issued to Hubble, III et al. on November 12, 1985.

Turning now to Figure 4, there is shown photodiode array 106 in greater detail. Preferably, photodiode array 106 is about 5 millimeter square. Photodiode array 106 receives a portion of the light rays transmitted through condenser lens 114. A central photodiode 126 receives the total reflected light rays or flux. The total reflected light rays or flux includes the specular component and the diffuse component of the reflected light rays or flux. Thus, central photodiode 126 generates an electrical signal proportional to the total reflected flux including the diffuse component and the specular component thereof. As shown, central photodiode 126 is preferably substantially elliptical. Edge photodiodes 128 and 130 are configured to compliment central photodiode 126 to complete photodiode array 106 which is substantially square in shape. Edge photodiodes 128 and 130 are substantially identical to one another, being shaped as mirror images of one another. Edge photodiodes 128 and 130 are positioned to receive only the diffuse component of the reflected light rays or flux transmitted through condenser lens 116. Hence, the electrical signal generated by edge photodiodes 128 and 130 is proportional to only the diffuse component of the reflected light rays or flux. Subtraction of the combined electrical signals of the edge photodiodes from the electrical signal from the central photodiode yields a resultant electrical signal proportional to the specular component of the reflected light rays. A block diagram illustrating the integrated circuit 107 used to determine the portion or fraction of the test area on photoconductive belt 10 covered with toner particles is shown in Figure 5.

As already mentioned, central photodiode 126 generates an electrical signal proportional to the the sum of the specular and diffuse components of the light rays. Central photodiode 126 is electrically connected to amplifier 132. The electrical output signals from edge photodiodes 128 and 130 are proportional to the diffuse component of the light rays. Photodiodes 128 and 130 are electrically connected, in parallel, to amplifier 134 whose output is fed to difference amplifier 136. When the gains of amplifiers 132 and 134 are properly calibrated, usually during manufacture, the output from difference amplifier 136 is a voltage proportional only to the specular component of the current in central photodiode 126. The output from amplifier 136 is further amplified by amplifier 138. The voltage output from amplifier 138 is proportional to the specular component of the reflected light rays. Amplifier 140 is connected to the output of amplifier 134. Since the output from amplifier 134 is directly proportional to the reflected diffuse light rays, amplifier 140 provides an output ranging from near 0 volts to about 10 volts that is a measure of the diffuse output viewing a test patch having toner particles deposited thereon.

In operation, the specular and diffuse voltage outputs are measured for the bare or undeveloped test area. The test area is then developed with black toner particles and the specular and diffuse voltage outputs are measured. The diffuse reflectivity of the undeveloped test area, i. e. bare photoconductive surface, is then calculated and used in subsequent measurements of the test area developed with color toner particles. Using these measurements,

$VS_{pr} = (GS)(RS_{pr})$

$VD_{pr} = (GD)(RD_{pr})$

$VS_{bt} = (1 - b)(VS_{pr}) + b(GS)(RS_{bt})$

Since the specular reflectivity, RS_{bt}, of black toner is zero,

$VS_{bt} = (1 - b)(GS)(RS_{pr})$

$VD_{bt} = (1 - b)(VD_{pr}) + b(GD)(RD_{bt})$

$VD_{b}t = (1 - b)(GD)(RD_{pr}) + b(GD)(RD_{bt})$

where:

VS_{pr} is the specular output voltage from densitometer 51 when viewing the bare photoconductive surface.

VD_{pr} is the diffuse output voltage from densitometer 51 when viewing the bare photoconductive surface.

GS is a specular proportionality constant.

GD is a diffuse proportionality constant.

RS_{pr} is the specular reflectivity of the photoconductive surface.

RD_{pr} is the diffuse reflectivity of the photoconductive surface.

RS_{bt} is the specular reflectivity of black toner particles (0.00).

RD_{bt} is the diffuse reflectivity of black toner particles (0.01).

VS_{bt} is the specular output voltage from densitometer 51 when viewing the test area developed with black toner particles.

VD_{bt} is the diffuse output voltage from densitometer 51 when viewing the test area developed with black toner particles.

b is the portion or fractional area of the test area recorded on photoconductive belt 10 that is covered with toner particles after development of the test area.

The diffuse proportionality constant, GD, may be expressed as:

$GD = [(VS_{pr})(VD_{bt}) - (VD_{pr})(VS_{bt})]/[(RD_{bt})(VS_{pr} - VS_{bt})$

By determining the diffuse and specular voltage outputs from densitometer 51 for a bare photoconductive surface and a test area developed

with black toner particles, the value for the diffuse proportionality constant, GD, may be obtained. The diffuse proportionality constant, GD, may be used to determine the diffuse reflectivity of the bare photoconductive surface from the following relationship:

$RD_{pr} = VD_{pr}/GD$

The diffuse output voltage from densitometer 51 when viewing the test area developed with colored toner particles, may be expressed as:

$VD_{ct} = (1\text{-}b)(GD)(RD_{pr}) + b(GD)(RD_{ct})$

where:

VD_{ct} is the diffuse output voltage from densitometer 51 when viewing the test area developed with colored toner particles.

RD_{ct} is the diffuse reflectivity of colored toner particles. The diffuse reflectivity of the colored toner is fixed at manufacture for each color of the colored toner particles and is a constant.

The portion or fractional area of the test area recorded on photoconductive belt 10 that is covered with toner particles after development of the test area, b, may be expressed as:

$b = [VD_{ct} - VD_{pr}]/[(GD)(RD_{ct}) - VD_{pr}]$

Inasmuch as VD_{pr}, is a measured value, GD is calculated from measured values, and RD_{ct} is a constant, b may be determined as a function of the diffuse output voltage from densitometer 51 when viewing the test area developed with colored toner particles, VD_{ct}. All of the foregoing calculations may be performed by the control logic of the electrophotographic printing machine and are based upon voltage outputs from densitometer 51. It is clear that VD_{pr}, GD and RD_{ct} are reference values which are stored by the control logic and used for all subsequent determinations of b. This approach requires only that the densitometer provide an output voltage proportional to the diffuse reflection of the colored toner after these references values have been determined.

In recapitulation, the densitometer described above measures the specular and diffuse reflectivity of the bare photoconductive surface and that of the test area developed with black toner particles. This information serves as reference values for determining the fractional area of the test area covered with colored toner particles as a function of the measured diffuse reflectivity of the test area developed with colored toner particles. This value is compared to a reference and an error signal generated if a specified minimum density of toner particles is not maintained, in response to which the concentration of toner particles in the relevant developer unit 44, 46, 48, 50 can be adjusted.

Claims

1. An apparatus for measuring the reflectivity of a selected region of a surface (10) covered at least partially with particles; including:
means for generating a first signal (VD_{ct}) proportional to the diffuse component of the total reflectivity of the selected region of the surface covered at least partially with particles and a first reference signal (VD_{pr}) proportional to the diffuse component of the total reflectivity of a region of the surface without particles thereon; and
means for determining a control signal as a function of the difference between the first signal and the first reference signal.

2. An apparatus according to claim 1, wherein:
said generating means generates a second reference signal (VS_{pr}) proportional to the specular component of the total reflectivity of the region of the surface without particles thereon, a third reference signal (VS_{bt}) proportional to the specular component of the total reflectivity of the selected region of the surface with black particles thereon, and a fourth reference signal (VD_{bt}) proportional to the diffuse component of the total reflectivity of the selected region of the surface with black particles thereon; and
said determining means determines a constant of proportionality GD as a function of the first reference signal, the second reference signal, the third reference signal and the fourth reference signal with the control signal being determined as a function of the constant of proportionality.

3. An apparatus according to claim 1 or claim 2, wherein said generating means includes means (102) for illuminating the surface.

4. An apparatus according to claim 3, wherein said illuminating means includes a light emitting diode.

5. An apparatus according to claim 3 or claim 4, further including means (104) for measuring and controlling the intensity of the light being emitted from said illuminating means.

6. An apparatus according to claim 5, wherein said measuring and control means includes a control photosensor positioned adjacent said illuminating means to detect the variation in intensity of the light being emitted from said illuminating means.

7. An apparatus according to any one of claims 3 to 6, further including a first condenser lens (116) interposed into the light path of said illuminating means so that collimated light rays are projected onto the surface.

8. An apparatus according to any one of the preceding claims, wherein said generating means (106) includes means for detecting the total reflectivity and the diffuse component of reflectivity.

9. An apparatus according to claim 8, further including a condenser lens (114) interposed between said detecting means and the surface for receiving the light rays reflected therefrom.

10. An apparatus according to claim 8 or claim 9, wherein said detecting means includes a photosensor array.

11. An apparatus according to claim 10, wherein said photosensor array includes:
a central photosensor (126) positioned to receive specularly-and diffusely-reflected light rays from the surface; and
at least one edge photosensor (128, 130) positioned about the periphery of said central photosensor to receive diffusely-reflected light rays from the surface.

12. An apparatus according to claim 11, wherein:
each photosensor comprises a photodiode.

13. An electrophotographic printing machine, including a movable photoconductive member and measuring apparatus as claimed in any one of the preceding claims for measuring the reflectivity of a selected region of the surface of the photoconductive member covered at least partially by marking particles.

14. A machine as claimed in claim 13, including developer apparatus operable to deposit marking particles on the surface of the photoconductive member, in which the control signal from the said measuring apparatus is applied to the developer apparatus to regulate the rate at which marking particles are deposited on the said surface.

15. A densitometer for measuring the reflectivity of a selected region of a moving photoconductive member (10) covered at least partially with marking particles, including
a collimating lens (116);
a light source (102) positioned to project light rays through said collimating lens onto the moving photoconductive member with or without marking particles thereon;
a collector lens (114) positioned to receive the light rays reflected from the moving photoconductive member;
a photosensor array (106) positioned to receive the light rays transmitted through said collector lens and operable to generate a first signal (VD_{ct}) proportional to the diffuse component of the total reflectivity of the selected region of the photoconductive member with marking particles covering at least a portion thereof and a first reference signal (VD_{pr}) proportional to the diffuse component of the total reflectivity of a region of the photoconductive member without marking particles thereon; and
control circuitry, electrically connected to said photosensor array, for determining a control signal as a function of the difference between the first signal and the first reference signal.

16. A method of measuring the reflectivity of a selected region of a photoconductive member (10) covered with diffusely reflecting marking particles, including the steps of:
generating reference voltages (VS_{pr}, VD_{pr}, VS_{bt}, VD_{bt}) proportional to the specular and diffuse components of the total reflectivity of the selected region of the photoconductive member without marking particles thereon and when covered at least partially with black marking particles;
determining a constant of proportionality (GD) as a function of the said reference voltages and the diffuse reflectivity (RD_{bt}) of black marking particles;
generating a diffuse output voltage (VD_{ct}) proportional to the diffuse component of the total reflectivity of the selected region of the photoconductive member with diffusely reflecting particles covering at least a portion thereof; and
determining the portion (b) of the selected region of the photoconductive member that is covered with diffusely reflecting marking particles as a function of the constant of proportionality (GD), the diffuse output voltage (VD_{ct}) and the reference voltage (VD_{pr}) proportional to the diffuse component of the total reflectivity of the region of the photoconductive member without marking particles thereon.

17. In a electrophotographic printing machine, the method of regulating the density of marking particles deposited on the photoconductive member, the method including the step of measuring the reflectivity of a selected portion of the photoconductive member by a method as claimed in claim 16, generating a control signal in dependence on the size of the determined portion (b) and using the control signal to regulate the rate at which marking particles are deposited on the photoconductive member.

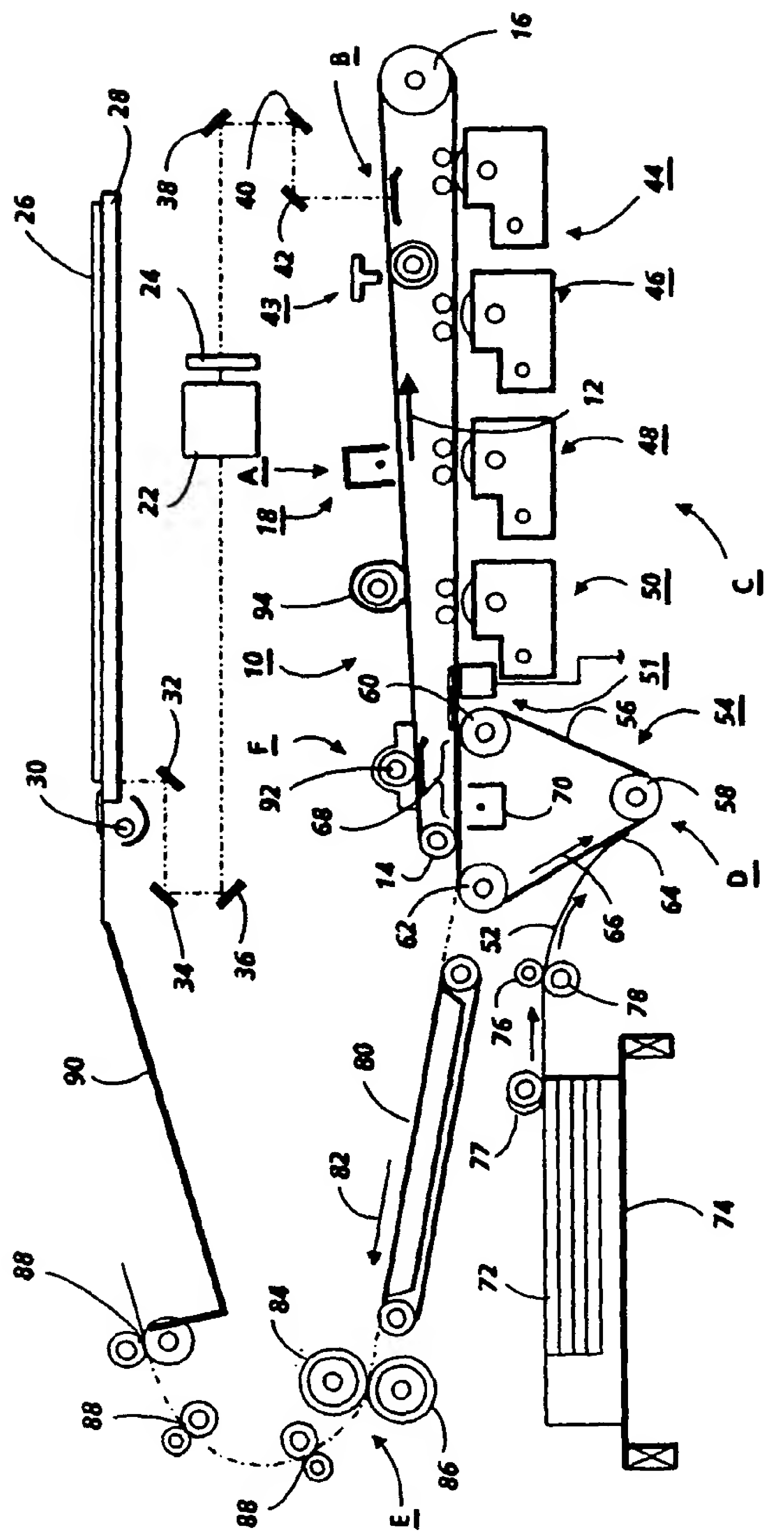

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FIG. 1

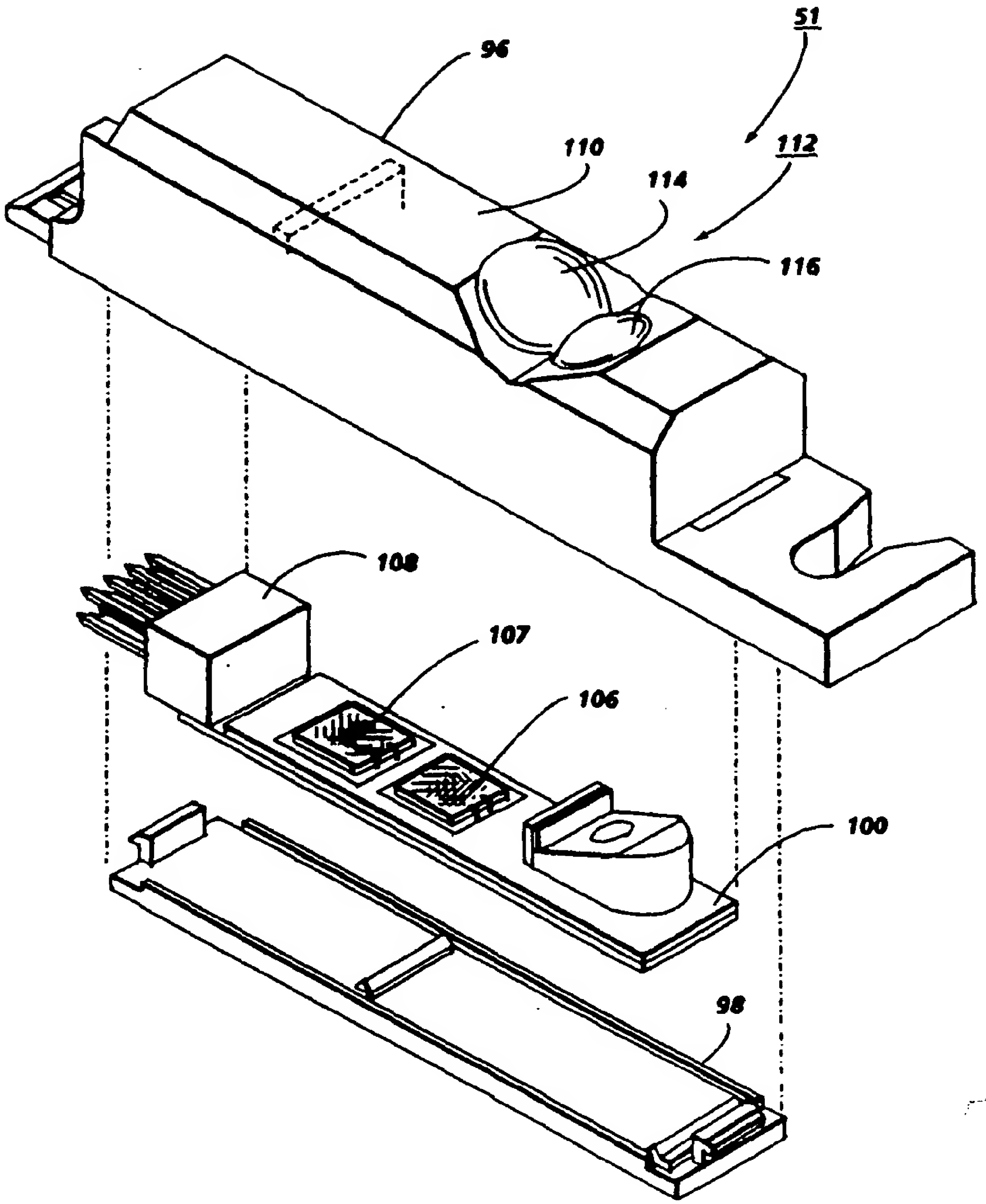

FIG. 2

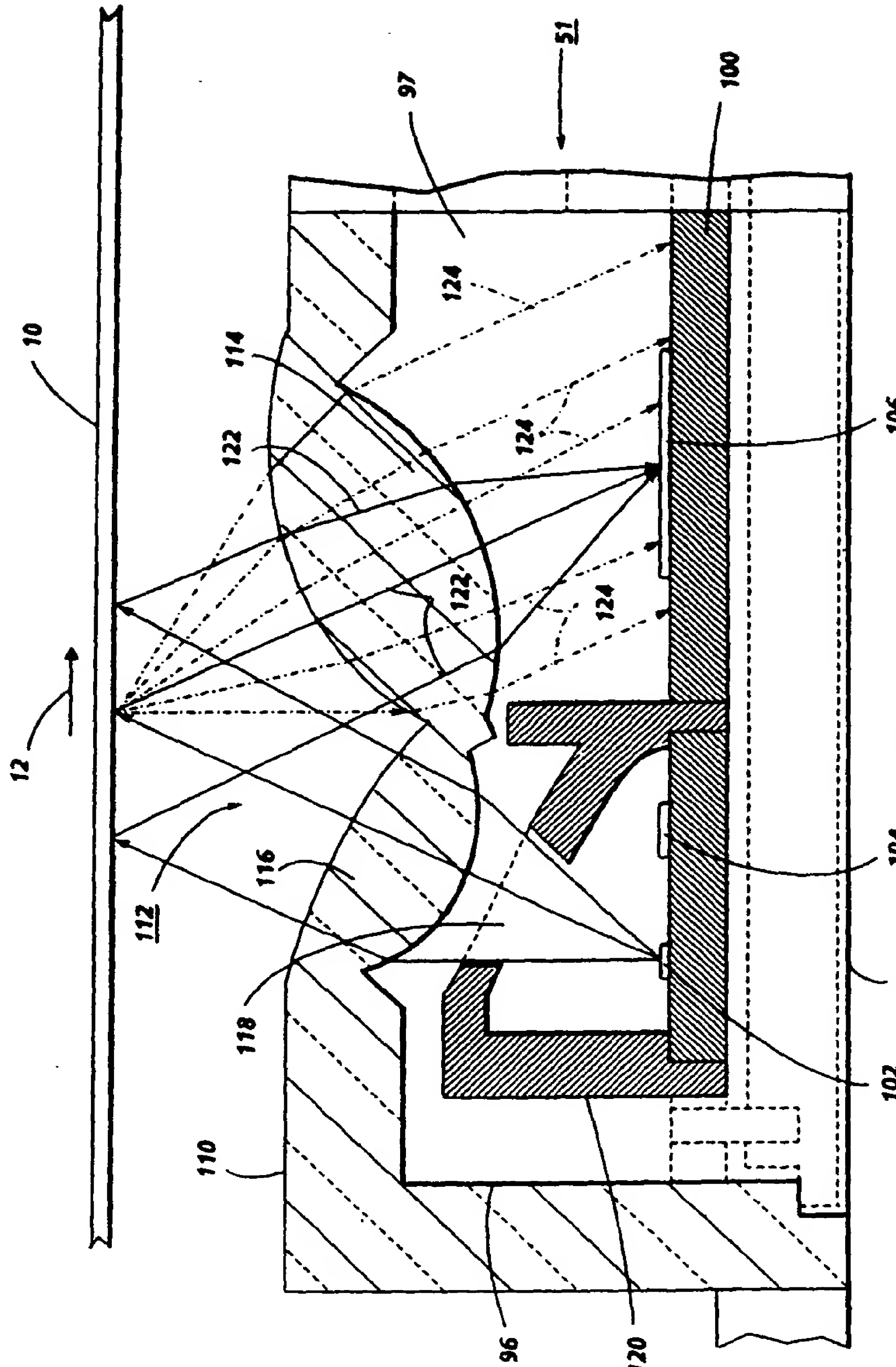
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FIG. 3

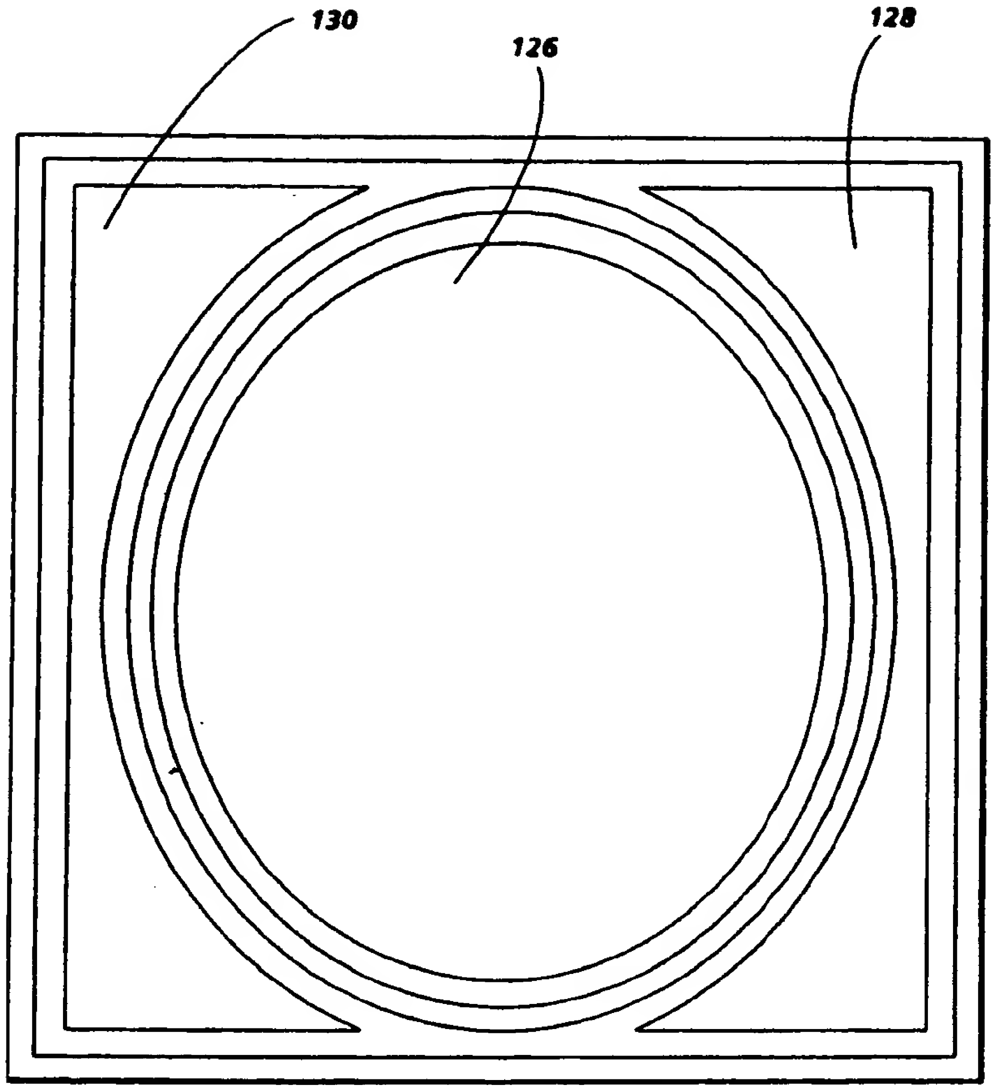

FIG. 4

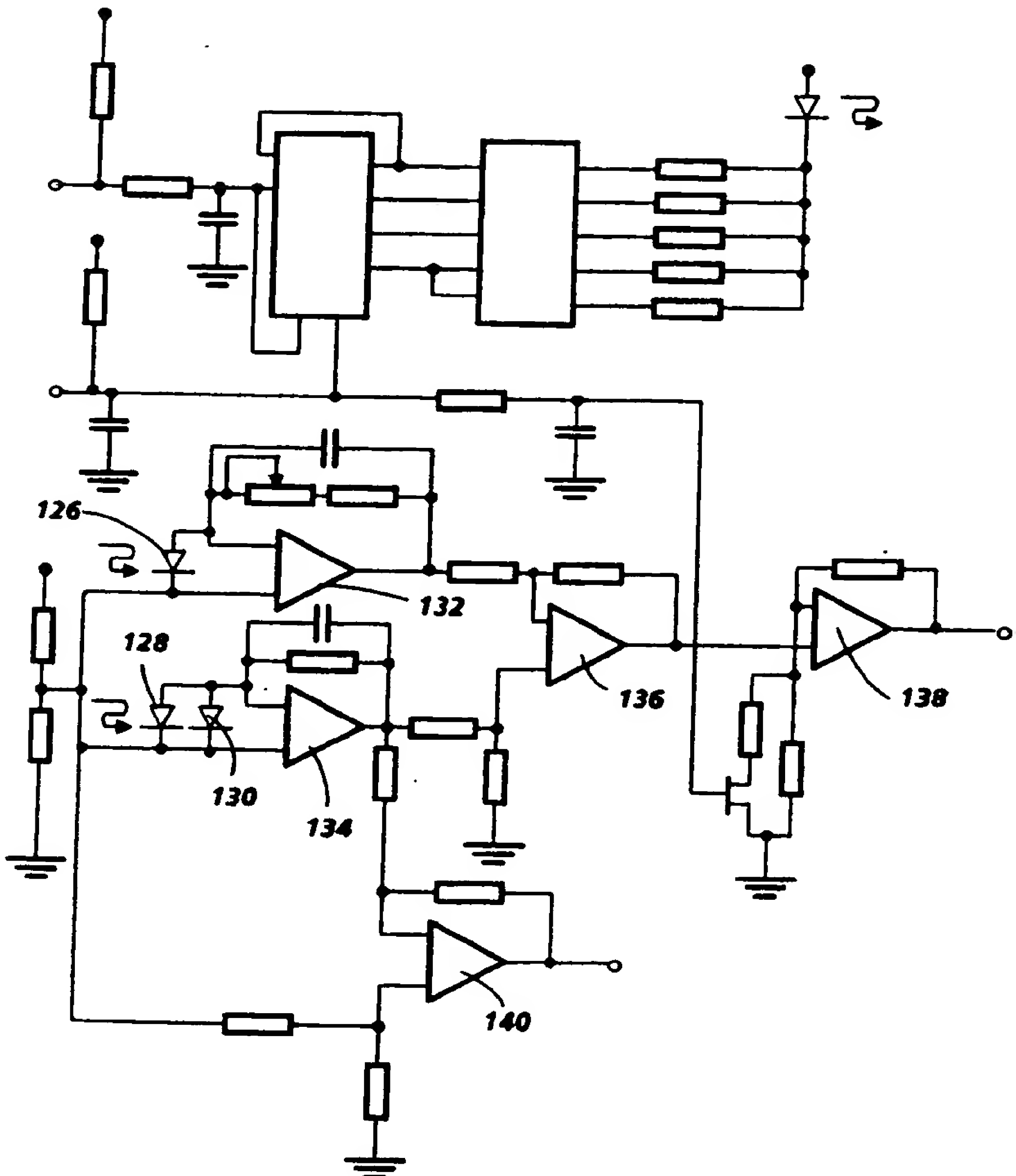

FIG. 5